Gaseous tidal debris found in the NGC 3783 group

Virginia A. Kilborn,1,2† Duncan A. Forbes,1 Bärbel S. Koribalski,2 Sarah Brough1 and Katie Kern1,2

1Centre for Astrophysics and Supercomputing, Swinburne University, Hawthorn, VIC 3122, Australia
2Australia Telescope National Facility, CSIRO, PO Box 76, Epping, NSW 1710, Australia

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ABSTRACT
We have conducted wide-field H I mapping of a ∼5.5 × 5.5-deg² region surrounding the NGC 3783 galaxy group, to an H I mass limit of ∼4 × 10⁸ M⊙. The observations were made using the multibeam system on the Parkes 64-m radiotelescope, as part of the Galaxy Evolution Multiwavelength Study. We find twelve H I detections in our Parkes data, four more than catalogued in H I Parkes All Sky Survey (HIPASS). We find two new group members, and discover an isolated region of H I gas with an H I mass of ∼4 × 10⁸ M⊙, without a visible corresponding optical counterpart. We discuss the likelihood of this H I region being a low surface brightness galaxy, primordial gas, or a remnant of tidal debris. For the NGC 3783 group we derive a mean recession velocity of 2903 ± 26 km s⁻¹, and a velocity dispersion of 190 ± 24 km s⁻¹. The galaxy NGC 3783 is the nearest galaxy to the luminosity-weighted centre of the group, and is at the group mean velocity. From the X-ray and dynamical state of this galaxy group, this group appears to be in the early stages of its evolution.

Key words: galaxies: clusters: general – galaxies: evolution – galaxies: irregular.

1 INTRODUCTION

The physical processes operating in galaxy groups are likely to be somewhat different to those operating in galaxy clusters. For example, the intragroup medium is significantly less dense than the intracluster medium and galaxy motions slower – suggesting that ram-pressure stripping is less effective in groups than in clusters (Mulchaey & Zabludoff 1998). On the other hand, as relative galaxy motions are smaller, gravitational interactions will be more effective and outright mergers more common in groups (Zabludoff & Mulchaey 1998).

Neutral hydrogen (H I) observations are a particularly useful method of probing the relative importance of ram-pressure stripping and tidal interactions. The H I is typically more extended than the optical disc of a galaxy, and thus is more sensitive to tidal interactions than the stars (e.g. Haynes, Giovanelli & Chincarini 1984), and ram-pressure stripping affects the gas rather than the stars in a galaxy. In addition, H I surveys can detect new, optically faint but gas-rich galaxies, previously unidentified in optical surveys (e.g. Banks et al. 1999; Kilborn et al. 2005). However, systematic, optically unbiased H I surveys of loose galaxy groups are few. These H I surveys of groups have found galaxies with extended H I envelopes (Haynes 1981), some galaxies with significant H I deficiencies (Kilborn et al. 2005; Omar & Dwarakanath 2005) and that there are no intergalactic H I clouds in groups similar to the Local Group (Zwaan 2001; Pisano et al. 2004).

Tidal interactions between gas-rich galaxies (e.g. Barnes & Hernquist 1996; Toomre & Toomre 1972) are known to produce H I bridges (e.g. Li & Seaquist 1994; Yun, Ho & Lo 1994; Koribalski & Dickey 2004; Koribalski & Manthey 2005), tails (e.g. Hibbard & Yun 1999; Hibbard et al. 2001b) or even ‘clouds’ that are spatially distinct from the host galaxy (e.g. Schneider 1985; Ryder et al. 2001; Bekki, Koribalski & Kilborn 2005a; Bekki et al. 2005b). Such H I clouds, with no obvious optical counterpart, have been detected in clusters (Giovanelli & Haynes 1989; Davies et al. 2004; Oosterloo & van Gorkom 2005) but their origin is not always immediately obvious (Djorgovski 1990; Minchin et al. 2005; Bekki et al. 2005a). Determining the origin of H I ‘clouds’ is vital. For example, cosmological n-body simulations of the Local Group predict many more dark matter haloes, than galaxies are optically observed in the Local Group (Klypin et al. 1999; Moore et al. 1999). Could these haloes be detected in an H I survey? Despite deep H I surveys of groups (Zwaan 2001; Pisano et al. 2004), and the HIPASS southern sky H I survey (Meyer et al. 2004), we are yet to identify any H I sources that are primordial, i.e. are not associated with a star-forming galaxy.

This paper describes H I observations of the NGC 3783 group, and in particular, the discovery of several new group members, and a region of H I emission that has no optical counterpart. This work is part of a larger investigation into the properties of galaxies in groups,
the Group Evolution Multiwavelength Study (GEMS). GEMS is a large survey of about 60 groups that were selected to have previous ROSAT PSPC X-ray observations (see Forbes et al. 2006). Osmond & Ponman (2004, hereafter OP04) detail the selection criteria and group properties for the 60 groups. We have made wide-field HI observations of 16 GEMS groups with the Parkes telescope. These observations will allow us to characterize the HI content of loose groups, and the relationship between H I content and X-ray emission. Kilborn et al. (in preparation) describe the HI subsample and characteristics.

The NGC 3783 group was first identified by Giuricin et al. (2000), who found three galaxies including the well-studied Seyfert galaxy NGC 3783. The group lies at a distance of 36 Mpc (OP04); at this distance, 1 arcsec = 174.5 pc. OP04 find extended X-ray emission surrounding NGC 3783, out to a radius of 69 kpc (see Section 3.2 for details).

We briefly discuss our HI observations and data reduction in Section 2, and the results from the wide-field HI imaging in Section 3. High resolution observations of NGC 3783 itself, and a nearby dwarf galaxy are presented in Section 4, and we discuss the discovery of a region of intragroup H I gas in Section 5. We finish with discussions in Section 6, and conclusions in Section 7. Throughout we use a heliocentric velocity in the optical convention.

2 OBSERVATIONS AND DATA REDUCTION

2.1 Parkes HI observations

Wide-field HI observations for the NGC 3783 group were conducted as part of the GEMS HI study (Kilborn et al. 2005; Kilborn et al. in preparation). The observations were made using the inner seven beams of the 20-cm multibeam system on the Parkes 64-m telescope in NSW, Australia. The area observed covers $\sim 5.5 \times 5.5$ deg$^2$ centred on the NGC 3783 galaxy group. The velocity range of the data is from 1979 to 3615 km s$^{-1}$. The observational strategy and subsequent data reduction are described in detail in Kilborn et al. (2005) and Kilborn et al. (in preparation). Approximately 25 h of data were obtained for this region. We used the AIPS++ routines livedata and gridzilla to reduce the data, in the same way that is explained in detail in Kilborn et al. (2005).

For this particular data set, approximately 30 per cent of the data was affected by solar interference, which produces a ‘ripple’ effect in the reduced data cube. While the H I detections in the cube are visible, the cube contains a number of artefacts and the data quality is variable both spatially and in velocity. Thus, a subsequent data cube was made from the remaining 70 per cent of ripple-free scans only. Although the rms noise for this data cube is slightly higher, the artefacts that had appeared in the original data cube are absent, and the rms is constant throughout the new data cube. The new, ripple-free, H I data cube has an rms noise of 26 mJy beam$^{-1}$ per channel, and the parameters for the data cube are given in Table 1. We smoothed this data cube to a velocity resolution of 13.2 km s$^{-1}$, and the rms noise in the smoothed cube is 11.8 mJy beam$^{-1}$ per channel. For the distance of this group, this gives a $3\sigma$ H I mass limit of $3.8 \times 10^8 M_\odot$ (assuming a Gaussian profile, and an H I velocity width of 50 km s$^{-1}$). The smoothed HI data cube was searched for H I detections visually, using the KARMA visualization package (see Kilborn et al. 2005; Kilborn et al. in preparation, for cube searching and source parametrization details).

2.2 ATCA observations

We obtained higher spatial resolution observations from the Australia Telescope Compact Array (ATCA) both through dedicated observing programs, and from the ATCA archive. Standard MIRIAD routines were applied to reduce the data, and ‘natural’ weighting was used in each case. We used the primary flux calibrator 1934-638 for all the observations. The full-width half-power primary beam of the ATCA is $\sim 33$ arcmin at 1.4 GHz. The observational details are summarized in Table 2.

3 H I CONTENT AND CHARACTERISTICS OF THE NGC 3783 GROUP

3.1 H I characteristics of the group

Fig. 1 shows a velocity integrated H I map from the Parkes data for the NGC 3783 group. The H I observations reveal a very loose grouping, that is not symmetrically distributed around the galaxy NGC 3783. We detect 12 sources in our Parkes HI data cube, including the galaxy NGC 3783 itself. Table 3 lists the H I position,

Table 1. Parkes narrow-band data cube parameters for the NGC 3783 group.

<table>
<thead>
<tr>
<th>Centre [h m s, δ (+/-)] (J2000)</th>
<th>11:37, -37:53</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gridded beam size (arcmin)</td>
<td>15.5</td>
</tr>
<tr>
<td>Cube size (&quot;)</td>
<td>5.5 x 5.5</td>
</tr>
<tr>
<td>Velocity range (km s$^{-1}$)</td>
<td>1979–3615</td>
</tr>
<tr>
<td>Channel width (km s$^{-1}$)</td>
<td>1.65</td>
</tr>
<tr>
<td>Velocity resolution (km s$^{-1}$)</td>
<td>2.6</td>
</tr>
<tr>
<td>rms noise per channel (mJy beam$^{-1}$)</td>
<td>26</td>
</tr>
</tbody>
</table>

Table 2. Details of high-resolution ATCA H I data obtained for galaxies in the NGC 3783 group. The columns are as follows: (1) GEMS galaxy number; (2) new observation (O), or archive data used (A); (3) observation dates; (4) ATCA array used for the observations; (5) total integration time obtained for source in hours; (6) ATCA beam size in arcsec$^2$; (7) spectral resolution of the final data cube (km s$^{-1}$); (8) rms noise level per channel of the final data cube (mJy beam$^{-1}$).

<table>
<thead>
<tr>
<th>No.</th>
<th>O or A</th>
<th>Observation dates</th>
<th>Array s$^{-1}$</th>
<th>Integration time (h)</th>
<th>Beam size (arcsec$^2$)</th>
<th>Spectral resolution (km s$^{-1}$)</th>
<th>rms (mJy beam$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>O</td>
<td>2006 January 28</td>
<td>750D</td>
<td>1.6</td>
<td>102 x 34</td>
<td>6.6</td>
<td>5.5</td>
</tr>
<tr>
<td>2</td>
<td>O</td>
<td>2004 March 03, 2006 January 25–26</td>
<td>750A, 750D</td>
<td>20</td>
<td>88 x 50</td>
<td>13.2</td>
<td>2.8</td>
</tr>
<tr>
<td>3</td>
<td>O</td>
<td>2006 January 27</td>
<td>750D</td>
<td>1.35</td>
<td>83 x 47</td>
<td>6.6</td>
<td>4.0</td>
</tr>
<tr>
<td>4, 5</td>
<td>A</td>
<td>2001 July 09</td>
<td>375</td>
<td>1</td>
<td>58 x 145</td>
<td>6.6</td>
<td>6.0</td>
</tr>
<tr>
<td>6</td>
<td>O</td>
<td>2004 November 12</td>
<td>750C</td>
<td>4.5</td>
<td>98 x 55</td>
<td>3.3</td>
<td>5.0</td>
</tr>
<tr>
<td>7</td>
<td>A</td>
<td>1993 October 09–10, 1993 September 29–30, 1996 October 17–18</td>
<td>1.5D, 750D, 1.5A</td>
<td>18.1</td>
<td>50 x 50</td>
<td>10.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>
There were four HI detections that have several optically catalogued sources (with velocities near that of the H I source) within our 10 arcmin search region. Those H I detections are GEMS_N3783_6, GEMS_N3783_4, GEMS_N3783_5 and GEMS_N3783_9. As described in Section 2.2, we observed GEMS_N3783_6 in higher spatial resolution at the ATCA. We found the H I was associated with at least two of the galaxies close to the central position of the Parkes H I detection (ESO 320-G 023 and ESO 320-G 026), and tentatively was made of the other galaxy in the region, 6DF J1149529–385431. Archive ATCA data for GEMS_N3783_4 and GEMS_N3783_5 was available. These two H I detections lie very close to one another in projection (separation of ∼2 arcmin), but are separated in velocity in the Parkes data by 114 km s\(^{-1}\). The ATCA observations confirm that GEMS_N3783_4 is associated with AM1147−371. However, the beam size of the ATCA observations was such that it was not possible to confirm whether GEMS_N3783_5 is associated with one, or both of ESO 378-G 023 and NGC 3903, so we list both in Table 3. We do not have any high-resolution imaging of GEMS_N3783_9, so we list all 4 nearby optical candidates in Table 3.

The HIPASS catalogue, HICAT, contains eight of the twelve galaxies we detected in our H I data cube (Meyer et al. 2004). Three of the detections that are not in HICAT have small H I fluxes, and the fourth, GEMS_N3783_5, appears to have been missed in HICAT.

Table 3. H I detections from our NGC 3783 Parkes data cube.

<table>
<thead>
<tr>
<th>No.</th>
<th>α, δ (J2000) (h m s), (° ′ ′′)</th>
<th>(v_{\text{sys}}) (km s(^{-1}))</th>
<th>(M_{\text{HI}}) (10(^8) M(_{\odot}))</th>
<th>Separation (arcmin)</th>
<th>Optical ID s(^{-1})</th>
<th>Velocity (km s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11:34:18, −37:09:39</td>
<td>3202 ± 7</td>
<td>34.0 ± 3.3</td>
<td>6.1</td>
<td>ESO 378-G 011</td>
<td>3245</td>
</tr>
<tr>
<td>2</td>
<td>11:31:32, −36:18:53</td>
<td>2733 ± 10</td>
<td>3.8 ± 1.3</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>11:28:06, −36:32:45</td>
<td>3018 ± 2</td>
<td>116.0 ± 5.4</td>
<td>0.4</td>
<td>ESO 378-G 003</td>
<td>3022</td>
</tr>
<tr>
<td>4</td>
<td>11:49:40, −37:30:50</td>
<td>3055 ± 1</td>
<td>21.0 ± 2.3</td>
<td>1.7</td>
<td>AM1147−371</td>
<td>2964</td>
</tr>
<tr>
<td>5</td>
<td>11:49:01, −37:29:47</td>
<td>2933 ± 2</td>
<td>51.1 ± 3.4</td>
<td>1.3</td>
<td>ESO 378-G 023</td>
<td>2932</td>
</tr>
<tr>
<td>6</td>
<td>11:49:33, −38:50:40</td>
<td>2991 ± 2</td>
<td>32.5 ± 2.9</td>
<td>1.8</td>
<td>ESO 320-G 024</td>
<td>3037</td>
</tr>
<tr>
<td>7</td>
<td>11:38:51, −37:47:38</td>
<td>2923 ± 2</td>
<td>38.0 ± 2.9</td>
<td>3.9</td>
<td>NGC 3783</td>
<td>2817</td>
</tr>
<tr>
<td>8</td>
<td>11:37:54, −37:56:04</td>
<td>2947 ± 5</td>
<td>21.0 ± 2.5</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>9</td>
<td>11:35:43, −38:02:08</td>
<td>2705 ± 5</td>
<td>59.5 ± 4.1</td>
<td>1.0</td>
<td>AM1133−374</td>
<td>2742</td>
</tr>
<tr>
<td>10</td>
<td>11:26:06, −37:51:26</td>
<td>2810 ± 5</td>
<td>7.2 ± 1.5</td>
<td>4.0</td>
<td>ESO 319-G 020</td>
<td>2823</td>
</tr>
<tr>
<td>11</td>
<td>11:21:57, −37:46:45</td>
<td>2740 ± 5</td>
<td>12.6 ± 2.0</td>
<td>7.2</td>
<td>ESO 319-G 015</td>
<td>2737</td>
</tr>
<tr>
<td>12</td>
<td>11:29:43, −37:16:59</td>
<td>3034 ± 7</td>
<td>13.7 ± 2.7</td>
<td>4.3</td>
<td>ESO 378-G 007</td>
<td>3041</td>
</tr>
</tbody>
</table>

The columns are (1) GEMS galaxy number; (2) fitted H I centre position; (3) H I systemic velocity in the optical convention; (4) H I mass for the detection using group distance of 36 Mpc; (5) distance of optical counterpart from centre of the H I emission; (6) optical counterpart s\(^{-1}\) for the H I detection; (7) velocity of the optical counterpart, from 6dFGS DR2, apart from AM1147−371 where the velocity is a previous H I measurement from Mathews, Gallagher & Littleton (1995). The errors are derived following Koribalski et al. (2004). Columns (2)–(4) are H I properties as derived from the Parkes data.
due to confusion with the nearby GEMS_N3783_4. The HIPASS rms in the region of the NGC 3783 group is $\sim$15–16 mJy beam$^{-1}$ per channel, which higher than our GEMS data that has an rms noise of 11.8 mJy beam$^{-1}$ per channel (smoothed to the same resolution as HIPASS).

We compare the H I fluxes between HICAT and GEMS and find there is excellent agreement for six of the eight galaxies that the two surveys have in common. There is a disagreement in H I flux for two of the galaxies that are in both HICAT and GEMS. The GEMS H I flux measurement for GEMS_N3783_6 is $\sim$45 per cent lower than the HICAT flux measurement (HIPASSJ1149$-$38a). In this case, the HICAT spectrum has an extremely uneven baseline and thus the GEMS flux is more reliable. In the case of GEMS_N3783_9, the GEMS flux is 30 per cent higher than the
3.2 X-ray characteristics of the group

X-ray observations of the NGC 3783 group were obtained from the ROSAT PSPC archive, and the data reduction is described in OP04. X-ray images for each galaxy group in the GEMS survey are available in Forbes et al. (2006). The resolution of the X-ray images are 30 arcsec. The X-ray emission is centred on the galaxy NGC 3783, and OP04 find NGC 3783 itself to have an extended X-ray halo, consistent with intragroup X-ray emission (see Fig. 3).

However, they were unable to fit a two-component model to the X-ray distribution, and thus were unable to distinguish the galaxy emission from the group X-ray emission. The extent of the X-ray emission in NGC 3783 is 69 kpc, which is low compared to other loose groups that typically have group X-ray haloes greater than 100 kpc in size (Mulchaey & Zabludoff 1998). The X-ray luminosity for NGC 3783 is low at log $L_X = 40.76 \pm 0.11$ erg s$^{-1}$.

3.3 Dynamical and optical properties of the NGC 3783 group

Using the NED and 6dFGS DR2 data bases, we find 44 galaxies within the region of our H I data cube, and between velocities 2500–3500 km s$^{-1}$. Of these, 31 (~70 per cent) have their only redshift from the 6dFGS DR2. We use all previously catalogued galaxies in the region, along with the new H I detections, to investigate the characteristics of this group. The velocities used in the calculations are 6dFGS DR2 velocity where available (79 per cent), then velocities from NED where available (15 per cent) and finally H I velocities (6 per cent). Parameters for the NGC 3783 group are shown in Table 4.

To determine the centre of the NGC 3783 group, we use a luminosity-weighted mean, based on the $K$-band magnitudes of the galaxies where available from two-Micron All-Sky Survey (2MASS). Those galaxies without a known $K$-band magnitude are given a magnitude of 13.5 (as in Brough et al. 2006). All galaxies within the extent of the H I cube, and with velocities $v_{sys} < 3500$ km s$^{-1}$ are included in the calculation. The luminosity-weighted centre is $\alpha, \delta$ (J2000) = 11:37:12, $-37:30:57.6$, and is marked on Fig. 1. This centre is closest to the galaxy NGC 3783 itself, at a distance of 267 kpc away. As NGC 3783 is the largest galaxy in the group, and with an extended X-ray halo it is expected to lie closest to the group dynamical centre.

Fig. 4 shows the velocity–distance distribution for the NGC 3783 group, with the mean velocity and velocity dispersion for the group overlaid. The mean velocity and velocity dispersion were calculated following Beers, Flynn & Gebhardt (1990). We calculate a mean velocity of $2903 \pm 26$ km s$^{-1}$ and dispersion of $190 \pm 24$ km s$^{-1}$ for the group. The velocity of the galaxy NGC 3783 is very close to the mean velocity of the group, at 2916 km s$^{-1}$ (from the H I data). Comparing these values to those in the literature, in the original determination of the group, Giuricin et al. (2000) found a median group velocity of 2854 km s$^{-1}$, which is slightly lower than our value. OP04 search for group members for NGC 3783 using NED galaxies within a radius of 0.25 Mpc (the radius at which the density of the group fall to 500 times the critical density of the Universe, calculated from the X-ray temperature of the group), and $\pm 3\sigma$ of the velocity dispersion of the group. However, under these strict criteria, they find no other catalogued galaxies lie in the group region. They quote the group velocity as 2917 km s$^{-1}$, which is the optical velocity of the galaxy NGC 3783 itself. Brough et al. (2006) use a friends-of-members algorithm to determine the members and characteristics of the NGC 3783 group, and find the group has nine members, a mean group velocity of 2826 $\pm 14$ km s$^{-1}$, and velocity dispersion of $118 \pm 37$ km s$^{-1}$.

The velocity distribution of the galaxies is also shown in Fig. 4, with a Gaussian centred on 2903 km s$^{-1}$, with a width of 190 km s$^{-1}$ overlaid. The distribution of the galaxies appears normal, with a
slight skewness to higher velocities. The velocity distribution of H\textsc{i} detected galaxies appears the same as for all galaxies in the region.

4 HIGH RESOLUTION OBSERVATIONS OF NGC 3783, AND A NEW DWARF GALAXY

We obtained ATCA archive H\textsc{i} observations of the galaxy NGC 3783 (see Table 2 for details). Along with the detection of NGC 3783, we detected GEMS\textsubscript{N3783}\textsubscript{8}, at a distance of \(\sim 15\) arcmin \((\sim 160\) kpc) from NGC 3783, and at a velocity of 2983 km s\(^{-1}\). The position of the H\textsc{i} emission from the ATCA data is \(\alpha, \delta\) (J2000) = 11:38:01.8, 37:57:59, which is directly centred on a previously uncatalogued dwarf galaxy. An ATCA H\textsc{i} map showing NGC 3783 and the new dwarf galaxy is shown in Fig. 5. Other faint galaxies are visible in the optical image of the observed field, but not detected in H\textsc{i}. GEMS\textsubscript{N3783}\textsubscript{8} lies near the edge of the optical image, and the ATCA flux may be underestimated. The ATCA position of GEMS\textsubscript{N3783}\textsubscript{8} is indicated in Fig. 1, and the parameters for GEMS\textsubscript{N3783}\textsubscript{8} are given in Table 5. GEMS\textsubscript{N3783}\textsubscript{8} lies between NGC 3783 and ESO 320-G 013 both spatially (190 and 120 kpc projected separation, respectively), and in velocity (166 and 35 km s\(^{-1}\), respectively).

5 INTRAGROUP H\textsc{i} GAS

There is one other H\textsc{i} detection that does not correspond with any previous NED or 6dFGS DR2 optically catalogued galaxy. For clarity, the noisy edge of the data was masked out in this image. The H\textsc{i} mass for the new dwarf galaxy measured in the ATCA data is \(7 \pm 2 \times 10^8\) M\(_\odot\), compared to an H\textsc{i} mass of \(2.1 \pm 0.25 \times 10^9\) M\(_\odot\) from our Parkes data, thus it appears that this dwarf galaxy has an extended H\textsc{i} component that was resolved out in the ATCA observations. It should be noted that as GEMS\textsubscript{N3783}\textsubscript{8} lies near the edge of the primary beam, the ATCA flux may be underestimated. The ATCA position of GEMS\textsubscript{N3783}\textsubscript{8} is indicated in Fig. 1, and the parameters for GEMS\textsubscript{N3783}\textsubscript{8} are given in Table 5. GEMS\textsubscript{N3783}\textsubscript{8} lies between NGC 3783 and ESO 320-G 013 both spatially (190 and 120 kpc projected separation, respectively), and in velocity (166 and 35 km s\(^{-1}\), respectively).
Table 5. New group members discovered in the NGC 3783 group. The positions and velocities were derived from ATCA follow-up data, apart from GEMS N3783_10, where these values were derived from the Parkes data. The columns are as follows: (1) GEMS source name; (2) previous optical ID; (3) right ascension, declination (J2000); (4) systemic velocity; (5) H I mass derived from the Parkes data; (6) H I mass derived from ATCA data.

<table>
<thead>
<tr>
<th>GEMS name</th>
<th>Optical ID</th>
<th>α, δ (J2000) (h m s⁻¹)</th>
<th>Velocity (km s⁻¹)</th>
<th>H I mass (PKS) (10⁸ M ☿)</th>
<th>H I mass (ATCA) (10⁸ M ☿)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEMS_N3783_2</td>
<td>–</td>
<td>11:31:27, -36:18:37</td>
<td>2731 ± 4</td>
<td>3.8 ± 1.3</td>
<td>1.9 ± 0.3</td>
</tr>
<tr>
<td>GEMS_N3783_8</td>
<td>–</td>
<td>11:38:02, -37:57:59</td>
<td>2983 ± 8</td>
<td>21 ± 2.1</td>
<td>7.0 ± 2.0</td>
</tr>
<tr>
<td>GEMS_N3783_10</td>
<td>ESO 319-G 020</td>
<td>11:26:06, -37:51:26</td>
<td>2810 ± 5</td>
<td>7.2 ± 1.5</td>
<td>–</td>
</tr>
<tr>
<td>ATCA_1134-37</td>
<td>–</td>
<td>11:34:02, -37:14:15</td>
<td>3141 ± 5</td>
<td>–</td>
<td>2.4 ± 0.6</td>
</tr>
</tbody>
</table>

GEMS_N3783_2. However, unlike GEMS_N3783_8, inspection of optical images obtained from the Second Generation Digital Sky Survey (DSS II), at the position of the H I detection showed no obvious corresponding optical emission.

We obtained higher resolution follow-up observations from the ATCA for GEMS_N3783_2, described in Table 2. The ATCA velocity integrated H I flux density map overlaid on the corresponding DSS II R-band image is shown in Fig. 6 and a close-up of the region is shown in Fig. 7. The peak column density of GEMS_N3783_2 is 7.5 × 10¹⁹ cm⁻². GEMS_N3783_2 has a total H I mass of M_HI = 3.8 ± 1.3 × 10⁸ M ☿, determined from the Parkes observations. The ATCA H I map is unresolved with the ATCA beam size of 88 × 50 arcsec². The H I parameters for GEMS_N3783_2 are given in Table 6. The H I mass detected by the ATCA is 1.9 ± 0.3 × 10⁸ M ☿, slightly lower than the Parkes observations, indicating we are missing some extended H I emission. We made optical observations in the region of this object with the Keck telescope on 2005 February 9 (see Fig. 7). Images in R and B bands do not show the presence of any low surface brightness galaxy down to a limiting surface brightness of B ∼ 22 mag arcsec⁻².

There are several small, faint optical sources within the H I emission region for GEMS_N3783_2. We obtained a short service time observation with the 2dF multifibre spectrograph on 2005 May 4 to obtain redshifts for nearby bright, resolved optical sources. The

Figure 6. Neutral hydrogen distribution of GEMS_N3783_2 and ESO 378-G 003 (GEMS_N3783_3), overlaid on the DSS II R-band image. The contours show the H I emission, and the levels are 0.15, 0.2, 0.4, 0.8, 1 Jy km s⁻¹. The ATCA beam of 88 × 50 arcsec² is shown in the bottom left-hand corner. Two separate ATCA pointings were used, and the noisy edge of the primary beam corrected H I data cubes have been masked out indicated by the dashed lines in the image. Along with GEMS_N3783_2, we detect 2MASX J11305018−3617531 in H I. Heliocentric velocities are indicated.
Figure 7. Neutral hydrogen distribution of GEMS_N3783_2 (left-hand side) and 2MASX JJ11305018−3617531 (right-hand side), overlaid on the DSS II R-band image. The contour levels are 0.15, 0.2, 0.3 Jy km s$^{-1}$. The ATCA beam of 88$\times$50 arcsec$^2$ is shown in the bottom left-hand corner. The insert shows the $B$-band Keck image for the region surrounding GEMS_N3783_2.

Table 6. Neutral hydrogen parameters of GEMS_N3783_2.

<table>
<thead>
<tr>
<th></th>
<th>Parkes</th>
<th>ATCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{1}H$ mass (10$^{8}$ $M_{\odot}$)</td>
<td>3.8 ± 1.3</td>
<td>1.9 ± 0.3</td>
</tr>
<tr>
<td>Velocity (km s$^{-1}$)</td>
<td>2730</td>
<td>2731</td>
</tr>
<tr>
<td>$\Delta v_{20}$ (km s$^{-1}$)</td>
<td>116</td>
<td>50</td>
</tr>
<tr>
<td>$\Delta v_{50}$ (km s$^{-1}$)</td>
<td>106</td>
<td>40</td>
</tr>
</tbody>
</table>

2dF spectrograph covers a 2dF which could encompass the region about GEMS_N3783_2 in the one pointing. Most of the sources we observed did not contain emission or absorption lines for us to determine a redshift from. No sources were found at the group velocity.

What is the origin of GEMS_N3783_2? We have little information as yet on the structure or velocity field of this H I region, making it hard to determine the origin by studying it. Examining Fig. 6, the nearest bright galaxy to GEM_N3783_2 is the early-type galaxy NGC 3706. There are several nearby dwarf galaxies, and the nearest gas-rich spiral galaxies are $\gtrsim$500 kpc away. We have obtained high-resolution ATCA H I observations of the nearest spiral galaxies. The H I distribution of ESO 378-G 003 is shown in Figs 6 and 8, and the H I distribution of ESO 378-G 011 is shown in Fig. 9.

ESO 378-G 003 lies at a projected distance of $\sim$235 kpc from NGC 3706, and $\sim$450 kpc from GEMS_N3783_2. ESO 378-G 003 shows an extended H I distribution, which is distorted on the SE side of the galaxy. The velocity contours shown in Fig. 8 show typical spiral rotation in the undisturbed side of the galaxy, while the extended part shows irregular rotation, indicating a tidal interaction.

Fig. 9 shows the H I distribution for ESO 378-G 011 overlaid on the DSS II R-band image. In our ATCA H I data cube, we also detect a previously uncatalogued dwarf galaxy, ATCA_1134-37, at the position $\alpha$, $\delta$ (J2000) = 11:34:03, −37:14:22. ESO 378-G 011 lies at a projected distance of $\sim$570 kpc from GEMS_N3783_2, and the H I distribution for the galaxy appears regular.

6 DISCUSSION

The NGC 3783 group is a loose group of galaxies, with diffuse X-ray emission centred on the galaxy NGC 3783 itself. What is the evolutionary state of this group – for example, is it virialized? The extent of the X-ray emission is 69 kpc, which is low for intragroup X-ray emission, and only a single component fit to the surface brightness profile of the X-ray emission was possible. For comparison,
Mulchaey & Zabludoff (1998) find that for nine X-ray detected groups it was possible to make a two component fit to the surface brightness of the X-ray emission, with the first component extending 20–40 kpc, and corresponding to emission from the galaxy, and the second component extending 100–300 kpc, and corresponding to diffuse intragroup X-ray emission.

The extent of the X-ray emission in the NGC 3783 group could be interpreted in two ways: the X-ray emission could emanate solely from the Seyfert galaxy NGC 3783 itself, or the X-ray emission could be from the combination of emission from NGC 3783, and the group potential of a newly forming galaxy group, perhaps one that is not yet virialized. Looking at the velocity distribution of the group, it is nearly normally distributed, usually a sign of a relaxed system of galaxies. However, the velocity–distance plot shown in Fig. 4 does not look like a typical virialized group. The galaxy NGC 3783 itself is the closest galaxy to the luminosity-weighted centre of the group, although it is 267 kpc from this centre, which is unusual for a virialized group (Brough et al. 2006). NGC 3783 lies at the mean velocity of the group. This group seems to display some characteristics of a virialized group, however the fact that the X-ray emission is centred on a late-type galaxy, and is offset from the centre of the group indicates that this may be an example of a group in the early stages of evolution.

In our neutral hydrogen survey of the NGC 3783 group, we found several new group members, and one region of HI emission that appears to have no stars associated with it. While there are many examples of isolated neutral hydrogen that has been removed from galaxies [e.g. HI rogues gallery (Hibbard et al. 2001a): http://www.nrao.edu/astrores/HIrogues/], this is one of the most extreme examples of isolated HI ever found. To date, all neutral hydrogen that has been found in emission can be associated with either galaxies, regions of stars or star formation.

There are three possible explanations for the existence of GEMS_N3783_2 in the NGC 3783 galaxy group. Either this is an extremely low surface brightness galaxy that we have been unable to detect optically yet, GEMS_N3783_2 is comprised of gas that has been removed from a galaxy in the past, or GEMS_N3783_2 is a primordial cloud of neutral hydrogen which has not formed stars.

If GEMS_N3783_2 is a low surface brightness galaxy, then the limits placed by our Keck observations are such that the central surface brightness must be less than 22 mag arcsec$^{-2}$ in the B band. Assuming a source size of about 10 arcsec (e.g. the size of the nearest dwarf galaxy to GEMS_N3783_2, 2MASX J11305018−3617531), then we would have detected a typical dwarf galaxy in our optical imaging. However, we are not sensitive to an extended low surface brightness galaxy, and deeper optical imaging is needed to confirm there is no stellar component to GEMS_N3783_2.

GEMS_N3783_2 may be a remnant of stripping of a gas-rich galaxy. It is unlikely that GEMS_N3783_2 was formed through ram-pressure stripping, as the hot gas in the NGC 3783 group is confined to the region around NGC 3783 itself, and that the projected distance of GEMS_N3783_2 from the X-ray emission is >500 kpc. GEMS_N3783_2 may have formed through a tidal interaction.
between a gas-rich galaxy, and one or more other galaxies in the group.

The nearest gas-rich galaxy to GEMS_N3783_2 is 2MASX J11305018−3617531, for which we detected an H I mass of $\sim 10^7 M_\odot$ in our ATCA observations. Given the H I mass of GEMS_N3783_2 at $\sim 4 \times 10^8 M_\odot$ is typical of a dwarf irregular galaxy (e.g. Hoffman et al. 1996; Salzer et al. 2002; Stil & Israel 2002), perhaps 2MASX J11305018−3617531 has been tidally influenced by NGC 3706, removing the majority of the H I from the galaxy. This seems unlikely as we do not detect a bridge of H I joining GEMS_N3783_2 and 2MASX J11305018−3617531, and to remove the majority of H I from a dwarf galaxy while leaving the stars intact would require an extremely extended H I distribution of the dwarf galaxy.

The nearest gas-rich spirals to GEMS_N3783_2 are ESO 378-G 003 and ESO 378-G 011, at a projected separation of $\sim 450$ and $\sim 570$ kpc, respectively. Given the large projected separation, and apparently undisturbed H I distribution of ESO 378-G 011, we do not consider that it is the origin of GEMS_N3783_2. On the other hand, ESO 378-G 003 is closer to GEMS_N3783_2, and importantly, is also very close to the bright early-type galaxy NGC 3706. ESO 378-G 003 displays evidence of tidal interaction in its irregular H I and velocity distribution on one side of the galaxy. If GEMS_N3783_2 was formed from the interaction of NGC 3706 and ESO 378-G 003, then using the difference in velocity of GEMS_N3783_2 and ESO 378-G 003, and the projected separation of $450$ kpc, the timescale for the interaction is $\sim 1.5$ Gyr. Of the many possibilities, this seems the most likely, but it requires deeper observations to confirm. Deeper observations might uncover further H I in the system, as in the case of the Leo cloud (Schneider, 1985), and the NGC 1490 system (Oosterloo et al. 2004).

Finally, could GEMS_N3783_2 be an isolated primordial H I cloud, that has lived quiescently forming no stars? Cosmological simulations of groups have predicted many more dark matter haloes than optical galaxies are seen observationally (e.g. Klypin et al. 1999; Moore et al. 1999; D’Onghia & Lake 2004). Perhaps GEMS_N3783_2 is an example of such a dark halo, containing primordial H I gas? While not impossible, this option does seem unlikely. Of our H I survey of 16 galaxy groups, GEMS_N3783_2 is the only detection that we have found which does not have an obvious galaxy associated with it. If GEMS_N3783_2 is primordial material, then it is the only example we have found of such an object in our H I survey, and thus the number of these objects appears to be very low. We note, that our survey of 16 groups has a mass limit of $\lesssim 5 \times 10^8 M_\odot$, so we are unable to say anything about the population of lower mass H I clouds, however other authors have not found any low mass H I clouds in deep H I studies of loose groups (Zwaan 2001; Pisano et al. 2004).

7 CONCLUSIONS

We have made a wide-field H I survey of the NGC 3783 galaxy group, using the Parkes radiotelescope. We found 12 H I detections in the region, of which one is a region of extended H I emission that we cannot match with corresponding optical emission. We believe the origin of this H I region is likely to be tidal debris rather than ram-pressure stripped, or primordial H I. We found two previously uncatalogued dwarf galaxies – one from our Parkes observations (GEMS_N3783_8), and one from high-resolution ATCA observations (ATCA_1134-37). We used the 6dFGRS DR2 and NED data bases to find previously catalogued galaxies in the region, and determine parameters for the NGC 3783 group. We calculate a mean velocity for the group of $2903 \pm 26$ km s$^{-1}$, and velocity dispersion of $190 \pm 24$ km s$^{-1}$. The NGC 3783 group is a rare example of a group at the early stage of its evolution. Comparison with other GEMS groups will help in determining the evolutionary path of galaxies within groups in general.

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REFERENCES

Bekki K., Koribalski B. S., Ryder S. D., Couch W. J., 2005b, 357, 21
Forbes D. A. et al., 2006, PASA, 23, 38
Jones D. H., Heath J. D., Saunders W., Rees M., Colless M., 2005, PASA, 22, 277
Gaseous tidal debris in the NGC 3783 group

Koribalski B. et al., 2004, AJ, 128, 16
Omar A., Dwarakanath K. S., 2005, JApA, 26, 1

Yun M. S., Ho P. T., Lo K. Y., 1994, Nat, 372, 530

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